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## SOME ATTEMPTS TO DETERMINE LONG WAVE POSITIONS

BY QUANTITATIVE MEANS

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### Introduction:

The existence of long waves in the circumpolar westerlies of the atmosphere has been known for some years, and the importance of such broad scale patterns in determining the various weather regimes is well known. Knowledge of the present and probable future positions of these atmospheric long waves is a valuable tool in preparing all forecasts except those of extremely short range, and the number of forecasters making daily use of long wave concepts is steadily increasing.

The usual methods, and in fact the only known methods at present, for determining the long wave positions make use of qualitative considerations or procedures which are at best only semi-quantitative in nature. In most cases this can be done satisfactorily. However, situations often arise in which the long wave pattern does not stand forth clearly, and at such times there is disagreement among forecasters as to the number of waves, their positions, and their future movement.

Since the long waves are physical in character and since they are a component of the contour configurations on upper air constant pressure charts, it would seem possible to devise a quantitative method for determining the positions of the long wave troughs and ridges on a given chart. The value of such a method is apparent especially for those situations in which the long waves are masked by the presence of short waves of large amplitude. Even though a quantitative method might prove to be too time consuming for application by all forecast offices, if a sufficiently reliable method can be devised it should be feasible for a weather central to perform the calculations and distribute the results to other forecast offices by teletype. With this objective in mind, various procedures were devised and tested.

### 2. Methods:

As an initial effort daily graphs were constructed with each graph representing a three day mean of the daily continuity charts. These continuity charts were constructed by plotting the mean height of the 500 mb. surface between latitudes 40°N and 50°N for each 10° of longitude from 110°E across North America to 20°E. The use of mean charts for determination of long wave patterns is not new. Their value lies in the fact that short waves move much more rapidly than the long waves, and consequently the short waves tend to cancel out on a mean chart. The Extended Forecast Section of the U. S. Weather Bureau has made use of this method for several years with construction of five day means a part of the regular routine. For the purpose of this study it was decided to use three day rather than five day means. This was decided for two reasons. First, the time lag between the mean chart and the current one is reduced which is obviously an advantage to one engaged in daily forecasting. Secondly, there appears to be a normal cycle of about three days for the passage of short waves

across a given meridian. Consequently, it was believed that selection of such a time interval would reduce the number of occasions in which an uneven number of short wave ridge and trough passages would be incorporated in the mean graph - for example, two ridge and one trough or two trough and only one ridge passages at any given meridian.

Three day mean graphs of the type described above were constructed daily for the period October 9 to December 19, 1951, and proved satisfactory in the majority of cases. However, any such mean chart based on fixed geographical coordinates is likely to be inadequate and often misleading when the long waves are moving at an appreciable rate or undergoing a period of readjustment and change in wave number. Furthermore, it is exactly in such instances that the long wave positions are most difficult to locate from qualitative considerations.

Since the circumpolar westerlies occasionally show a marked degree of eccentricity in respect to the geographic North Pole, a refinement of the above method was attempted. The height of the 500 mb. surface was tabulated at the intersections of standard meridians with circles lying in the belt of westerlies and concentric to the circulation pole rather than at intersections of the standard latitude and longitude lines. While this procedure resulted in removal of some irregularities from the three day mean graphs, the improvement was not sufficient to warrant recommendation of the method.

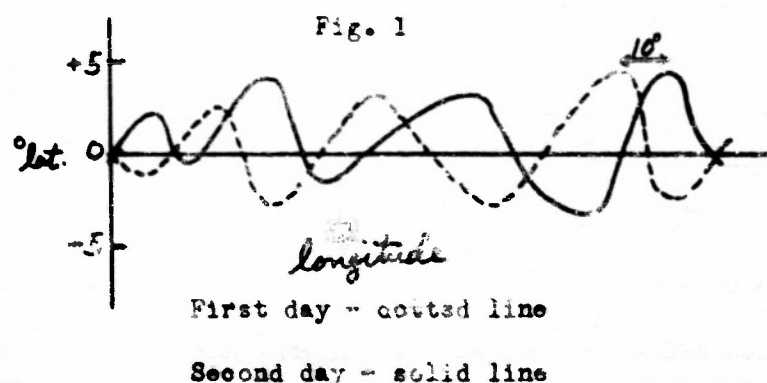
Another refinement attempted was the use of a moving system of coordinates based upon the displacement of the long wave pattern as calculated from the familiar Rossby equation. Thus each point of the three day mean graph was composed of values tabulated, not from the same longitude each day, but rather from three successive longitudes having the same relative position to the long wave pattern. For example in composing the three day mean, the value tabulated from a point which lay in the center of a long wave ridge on the first day of the period would have added to it values tabulated on the two following days at points which also lay in the center of the long wave ridge, providing the Rossby calculation correctly indicated the amount of daily displacement of the long wave pattern. In practice this attempt was unsuccessful largely because all portions of a long wave pattern do not move with the same speed. In order to remedy this situation the method put forth by Cressman<sup>1</sup> for calculating the displacement of an individual trough was considered. However, this method is more time consuming and is valid only when the long wave pattern is well established and conserved throughout the period. Consequently, there is no hope for quantitative determination of the long wave positions from these calculations when the long waves are in a period of readjustment, and it is precisely at such times that a quantitative method is most needed.

In view of the above difficulties an entirely different approach was decided upon - namely that of locating the short waves, calculating their amplitude, and subtracting the short wave pattern from the given map thereby leaving only the long wave pattern. Short waves are progressive, but the displacements usually involve meridional components of considerable magnitude due to the general tendency of short waves to proceed along the configuration of the long wave pattern. The height rise and fall areas associated with the short waves often migrate into or pass from any chosen latitude belt thereby constituting another serious disadvantage in the use of fixed geo-

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<sup>1</sup>Journal of Meteorology - February, 1949.

graphical coordinates. In order to overcome this difficulty the use of a fixed latitude belt was discarded, and a 500 mb. contour which passed completely around the hemisphere in unbroken fashion for several successive days was selected. (In this case the 18,000 foot contour was used). The latitude of this contour was tabulated daily for each 5 or 10 degrees of longitude, and each day from these latitude values were subtracted the values which had been tabulated at corresponding meridians on the previous day. The resulting daily changes in latitude of the contour were then plotted on a graph of latitude change versus longitude. Comparison of these graphs revealed the daily progression and changes in magnitude of the various rise and fall areas which were assumed to be associated with the short waves. (See figure 1.)



Such a graph shows only the number of degrees of longitude per day crossed by each rise and fall area. Actually meridional components are also involved in the movement of such systems, and in order to obtain the total displacement per day it was necessary to measure, along the contour on the 500 mb. chart, the distance traveled by a particular rise or fall maximum in crossing the meridians indicated on the graph. Thus the meridional components of movement were taken into account, and the speed  $C$  of each rise and fall maximum was determined. The distance (also measured along the contour) from a rise (fall) maximum to the next upstream fall (rise) maximum was then determined. If we call this distance  $L$ , it follows that the time,  $T$ , required for one-half of the short wave in question to pass a fixed point is given by,  $T = L/C$ .

The amplitude of a short wave in degrees of latitude can be obtained from the formula<sup>2</sup>

$$A = \frac{1}{2} b T$$

in which  $T$  is the time in days as defined above, and  $b$  is the average rate at which the latitude of the contour is changing, expressed in degrees of latitude per day. The value of  $b$ , for each rise and fall area appearing on the graph of latitude change versus longitude, was determined graphically as shown in Figure 2. The rectangles were drawn in such a manner that the sum of areas 1 and 2 was equal to area 3 in each case. The altitude of

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<sup>2</sup>Formula derived by Riehl.

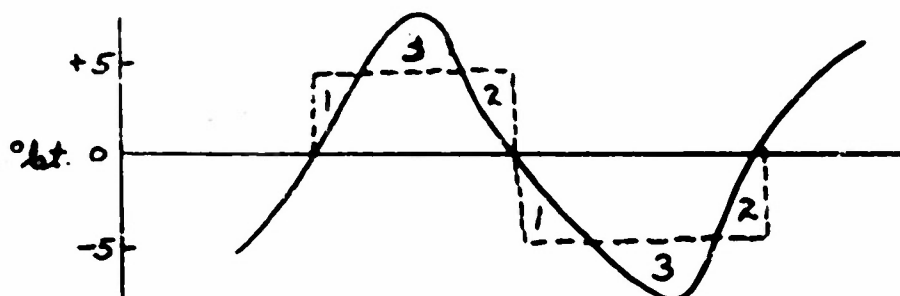


Figure 2

the rectangle was then read from the daily latitude change scale at the left and the absolute value taken to equal  $b$ . The amplitude of each short wave trough and ridge was then calculated by solving the formula  $A = \frac{1}{2} b T$  for each case.

Since 24 hr. tendencies were involved, the map time positions of the short wave troughs and ridges were assumed to be located twelve hours downstream from the corresponding zero points on the latitude change versus longitude graph. These positions were approximated by noting the 24 hour eastward displacement of each zero point and extrapolating one-half of that displacement. The calculated amplitude values were plotted at the appropriate longitude on an amplitude versus longitude graph and the points connected to give the short wave pattern. (See figure 3.)

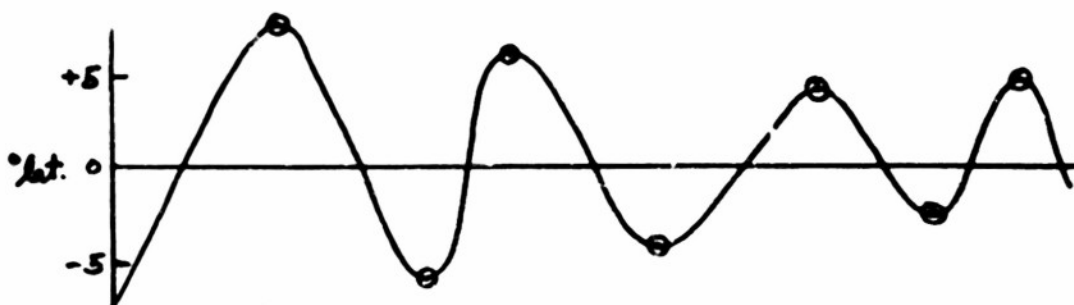


Figure 3

The resulting short wave pattern was removed from the map by tabulating values from the short wave graph for each longitude and applying these corrections to the original tabulation of latitudes for the contour - subtracting for the short wave ridges and adding for the troughs. The corrected latitude values were then plotted against longitude to find the shape and positions of the long waves.

### 3. Results:

The case to which this procedure was first applied was one in which the long wave pattern was clearly defined and undergoing little change. Results were satisfactory as indicated by Figure 4. Subsequently, the

procedure was applied to a number of cases selected from November and December of 1951 with varying results.

One ever-present difficulty was that arising from the impossibility of obtaining perfect 500 mb. analyses over Asia and the large ocean areas. Such errors were often apparent in the irregularity and failure of various patterns to follow through from day to day on the latitude change versus longitude graph. Reanalysis removed some of these unlikely patterns. In many cases considerable smoothing was necessary and was done assuming symmetry of the short wave pattern. Obviously such an assumption, although providing improvement, is likely to leave errors of appreciable magnitude, especially in regard to the amplitude of a particular short wave. Nevertheless, reasonable long wave patterns were obtained in nearly all cases in which the long waves were undergoing no marked changes.

Far more serious than the problem of analysis were the changes of intensity and in wave number of the long waves themselves. The tendencies appearing on the latitude change versus longitude graph involve components due to motion and intensity changes of the long waves as well as the short wave pattern. While this was expected from the outset, it was hoped that such components would be small. In a number of instances the results indicated otherwise. Figure 5 shows the very poor results obtained from such a case in which the long waves were undergoing a change in number and amplitude. Reanalysis and smoothing of the graphs failed to produce a satisfactory result. Examination of the latitude change versus longitude graph often gives rather obvious indications of intensity changes in the long waves, and some allowances can be made for this effect. However, there is no method at present for determining the magnitude of the correction to be applied, and no suggestions for a relatively simple solution have been forthcoming.

One unexpected result, and perhaps the most worthwhile one obtained from this study, was the indication that the number of short waves existing at the 500 mb level at any given time is rather small - far less than the number of low pressure areas appearing on the surface map. The daily number of short waves as revealed by this study ranged from five to ten. While there was usually some question as to the exact situation over Asia and some parts of the ocean areas, the evidence indicates that the above statement is essentially correct. Apparently there are many surface systems which are not associated with short waves at the 500 mb. level, or other wave trains exist which are too small in amplitude to be detected by the methods used to date.

#### 4. Conclusions:

- (1) Graphs representing three-day means of the continuity chart are a valuable aid in determining the long wave pattern in most cases, but must be used with caution, if at all, during periods when other considerations indicate changing wave number or considerable movement of the long waves.
- (2) Mean graphs based upon an eccentric grid show some improvement over those based upon a fixed latitude belt. However, the improvement obtained in more than a month of cases studied was slight.

- (3) A system using a moving rather than a fixed system of coordinates is desirable, but present computational methods for determining the movement of the long waves are too restrictive in their applications to be of much aid in constructing three-day means of the continuity chart.
- (4) Determination and removal of the short wave pattern in order to arrive at the long wave pattern is often possible but usually difficult due to areas of sparse data. Furthermore, the desired results will not be obtained during periods of appreciable change in long wave configuration until some method is devised by which the tendencies caused by the changing long wave pattern can be separated from the tendencies caused by the short waves.
- (5) The number of short waves discernible by present methods at the 500 mb. level is far less than the number of surface disturbances. Therefore, it appears that many surface systems have no association with an upper level wave train, or additional wave trains of very small amplitude exist in the atmosphere.

While some quantitative method for determining long wave positions is needed, no method has been found which maintains reliability during periods of marked change in the long wave pattern.

FIGURE 4

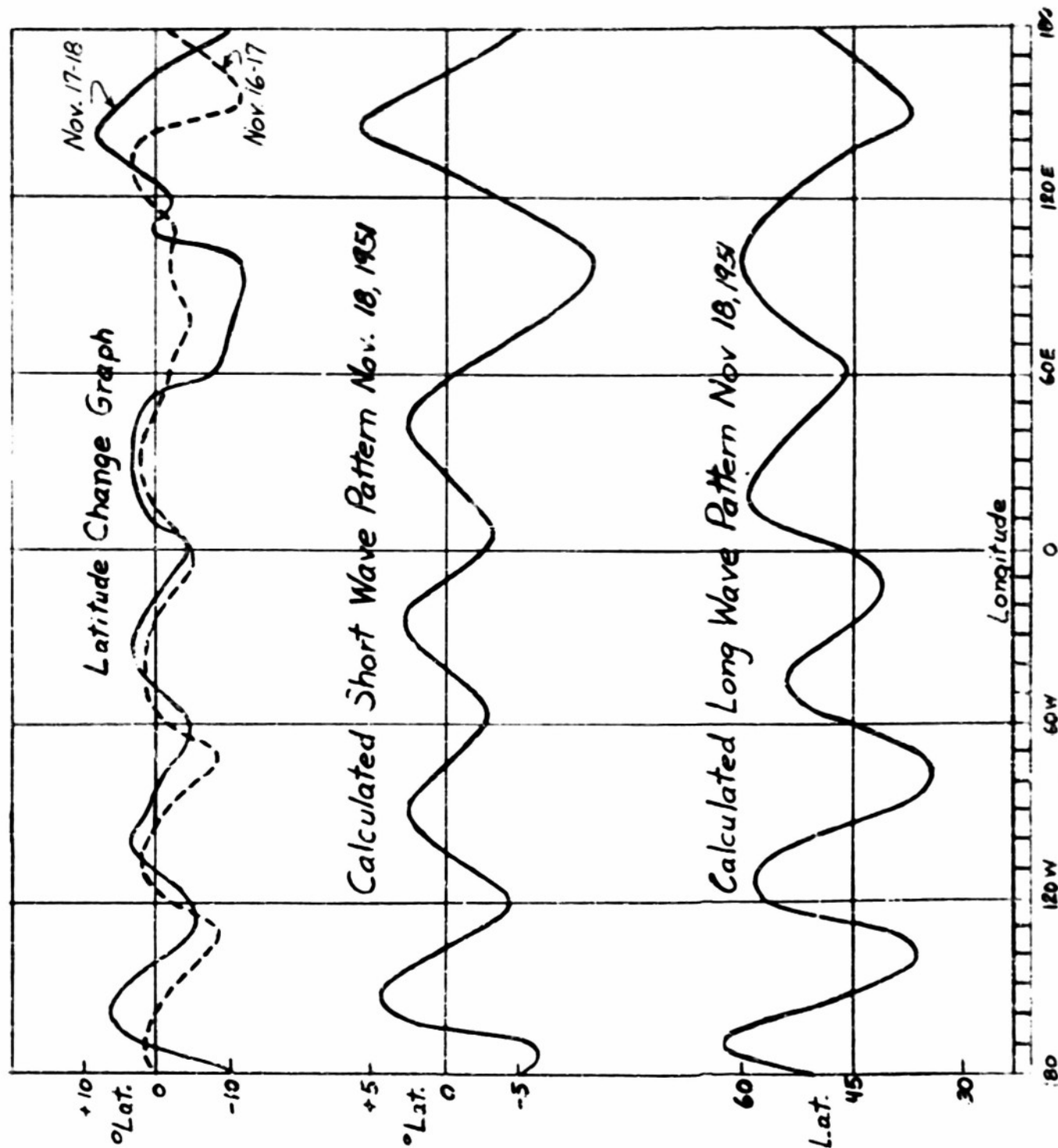




FIGURE 5

